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(54) **SYSTEM AND METHOD FOR ANKLE
ARTHROPLASTY**

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CPC **A61F 2/4202** (2013.01); **A61F 2002/4205**
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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,140,712 A * 7/1964 Hunter 623/18.12
3,521,302 A * 7/1970 Muller 623/18.11
3,839,742 A * 10/1974 Link 623/21.18
3,872,519 A * 3/1975 Giannestras et al. 623/21.18
3,879,767 A * 4/1975 Stubstad 623/21.19
3,889,300 A * 6/1975 Smith 623/21.18
3,896,502 A * 7/1975 Lennox 623/21.18

(Continued)

FOREIGN PATENT DOCUMENTS

FR 2803191 A1 7/2001
WO 95/30388 A1 11/1995

(Continued)

OTHER PUBLICATIONS

International Search Report, PCT/US04/20456, dated Jun. 7, 2005.
(Continued)

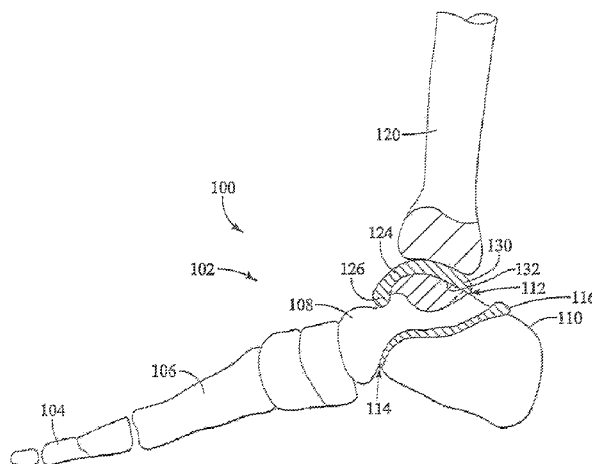
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(57) **ABSTRACT**

A monolithic interpositional arthroplasty implant for use in
repairing gyngylmus joints such as the joints of the ankle. The
implant is a monolithic tibiotalar implant having a first major
surface shaped to be positioned against a tibia. The tibia is
allowed to articulate across the first major surface. A second
major surface is shaped to be positioned against the talus.

17 Claims, 6 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

3,896,503	A *	7/1975	Freeman et al.	623/21.18	8,211,041	B2 *	7/2012	Fisher et al.	600/595
3,975,778	A *	8/1976	Newton, III	623/21.18	8,292,954	B2 *	10/2012	Robinson et al.	623/14.12
3,987,500	A *	10/1976	Schlein	623/21.18	8,292,955	B2 *	10/2012	Robinson et al.	623/14.12
D242,957	S *	1/1977	Treace	D24/155	8,337,503	B2 *	12/2012	Lian	606/87
4,021,864	A *	5/1977	Waugh	623/21.18	8,357,203	B2 *	1/2013	White et al.	623/21.11
4,069,518	A *	1/1978	Groth et al.	623/21.18	8,403,985	B2 *	3/2013	Hodorek	623/14.12
4,344,193	A *	8/1982	Kenny	623/14.12	8,506,637	B2 *	8/2013	Schwartz	623/17.17
4,385,404	A *	5/1983	Sully et al.	128/898	8,556,971	B2 *	10/2013	Lang	623/14.12
4,450,591	A *	5/1984	Rappaport	128/898	8,568,487	B2 *	10/2013	Witt et al.	623/22.12
4,467,479	A *	8/1984	Brody	128/898	8,574,305	B2 *	11/2013	Sanders et al.	623/21.18
4,470,158	A *	9/1984	Pappas et al.	623/20.21	8,585,744	B2 *	11/2013	Duggal et al.	606/301
4,755,185	A *	7/1988	Tarr	623/23.4	8,591,595	B2 *	11/2013	Kofoed et al.	623/21.18
5,171,322	A	12/1992	Kenny		8,597,361	B2 *	12/2013	Sidebotham et al.	623/18.11
5,326,365	A *	7/1994	Alvine	623/21.18	8,603,180	B2 *	12/2013	White et al.	623/22.11
5,556,429	A	9/1996	Felt		2001/0027345	A1	10/2001	Merrill et al.	
5,593,445	A *	1/1997	Waits	623/23.42	2002/0007219	A1	1/2002	Merrill et al.	
5,766,259	A *	6/1998	Sammarco	623/21.18	2002/0127264	A1	9/2002	Felt et al.	
5,782,924	A *	7/1998	Johnson	623/18.11	2002/0156531	A1	10/2002	Felt et al.	
5,795,353	A	8/1998	Felt		2002/0183850	A1	12/2002	Felt et al.	
5,824,106	A *	10/1998	Fournol	623/21.18	2002/0189622	A1 *	12/2002	Cauthen et al.	128/898
5,879,387	A *	3/1999	Jones et al.	623/18.11	2003/0093152	A1 *	5/2003	Pedersen et al.	623/14.12
6,110,411	A	8/2000	Clausen et al.		2003/0097182	A1	5/2003	Buchman et al.	
6,132,468	A	10/2000	Mansmann		2003/0181985	A1 *	9/2003	Keller et al.	623/21.18
6,140,452	A	10/2000	Felt et al.		2004/0030399	A1 *	2/2004	Asencio	623/21.18
6,183,519	B1 *	2/2001	Bonnin et al.	623/21.18	2004/0088052	A1 *	5/2004	Dearnaley	623/16.11
6,281,264	B1	8/2001	Salovey et al.		2004/0092942	A1 *	5/2004	Reiley	606/87
6,306,177	B1	10/2001	Felt et al.		2004/0107000	A1	6/2004	Felt et al.	
6,436,137	B2	8/2002	Wang et al.		2004/0117027	A1 *	6/2004	Reiley	623/21.18
6,436,146	B1	8/2002	Hassler et al.		2004/0133276	A1 *	7/2004	Lang et al.	623/14.12
6,494,917	B1	12/2002	McKellop et al.		2004/0133282	A1 *	7/2004	Deffenbaugh et al.	623/21.18
6,540,768	B1	4/2003	Diaz et al.		2004/0148026	A1 *	7/2004	Bonutti	623/16.11
6,540,786	B2 *	4/2003	Chibrac et al.	623/18.11	2004/0186585	A1 *	9/2004	Feiwell	623/21.18
6,547,828	B2	4/2003	Scott et al.		2004/0267277	A1 *	12/2004	Zannis et al.	606/99
6,652,587	B2	11/2003	Felt et al.		2005/0004676	A1	1/2005	Schon et al.	
6,673,116	B2	1/2004	Reiley		2005/0033424	A1 *	2/2005	Fell	623/14.12
6,677,415	B1	1/2004	O'Connor et al.		2005/0043808	A1 *	2/2005	Felt et al.	623/20.14
6,686,437	B2	2/2004	Buchman et al.		2005/0049710	A1 *	3/2005	O'Driscoll et al.	623/20.11
6,726,727	B2	4/2004	Scott et al.		2005/0049711	A1 *	3/2005	Ball	623/21.18
6,786,933	B2	9/2004	Merrill et al.		2005/0146070	A1 *	7/2005	Muratoglu et al.	264/85
6,800,670	B2	10/2004	Shen et al.		2005/0182492	A1 *	8/2005	Pappas et al.	623/21.18
6,814,757	B2 *	11/2004	Kopylov et al.	623/21.11	2005/0221703	A1 *	10/2005	Stone	442/123
6,852,130	B2	2/2005	Keller et al.		2005/0288792	A1 *	12/2005	Landes et al.	623/21.18
6,866,684	B2 *	3/2005	Fell et al.	623/20.3	2006/0004378	A1 *	1/2006	Raines et al.	606/99
6,926,739	B1	8/2005	O'Connor et al.		2006/0004460	A1 *	1/2006	Engh et al.	623/20.21
6,966,928	B2 *	11/2005	Fell et al.	623/14.12	2006/0009853	A1 *	1/2006	Justin et al.	623/20.3
7,004,971	B2 *	2/2006	Serhan et al.	623/17.16	2006/0020345	A1 *	1/2006	O'Connor et al.	623/21.18
7,025,790	B2 *	4/2006	Parks et al.	623/21.18	2006/0142870	A1 *	6/2006	Robinson et al.	623/21.18
7,037,342	B2 *	5/2006	Nilsson et al.	623/21.15	2006/0149261	A1 *	7/2006	Nilsson et al.	606/72
7,077,865	B2 *	7/2006	Bao et al.	623/17.12	2006/0224244	A1 *	10/2006	Thomas et al.	623/20.28
7,166,650	B2	1/2007	Muratoglu et al.		2006/0229730	A1 *	10/2006	Railey et al.	623/21.18
7,244,273	B2 *	7/2007	Pedersen et al.	623/14.12	2006/0235517	A1 *	10/2006	Hodorek	623/14.12
7,297,161	B2 *	11/2007	Fell	623/14.12	2006/0241758	A1 *	10/2006	Peterman et al.	623/17.11
7,304,097	B2	12/2007	Muratoglu et al.		2006/0241778	A1 *	10/2006	Ogilvie	623/21.15
7,323,012	B1 *	1/2008	Stone et al.	623/21.18	2006/0247788	A1 *	11/2006	Ross	623/21.18
7,507,774	B2	3/2009	Muratoglu et al.		2006/0293760	A1 *	12/2006	DeDeyne	623/23.76
7,534,270	B2 *	5/2009	Ball	623/21.18	2007/0027547	A1 *	2/2007	Rydell et al.	623/21.18
7,569,620	B2	8/2009	Muratoglu et al.		2007/0050038	A1 *	3/2007	Snell et al.	623/17.16
7,611,653	B1 *	11/2009	Elsner et al.	264/255	2007/0051180	A1 *	3/2007	White	73/760
7,635,725	B2	12/2009	Bellare et al.		2007/0078517	A1 *	4/2007	Engh et al.	623/20.3
7,776,097	B2 *	8/2010	Tepic et al.	623/22.24	2007/0100450	A1 *	5/2007	Hodorek	623/14.12
7,796,791	B2 *	9/2010	Tsougarakis et al.	382/128	2007/0112431	A1 *	5/2007	Kofoed	623/21.18
7,883,653	B2 *	2/2011	Smith et al.	264/248	2007/0112432	A1 *	5/2007	Reiley	623/21.18
7,909,882	B2 *	3/2011	Stinnette	623/23.41	2007/0118218	A1 *	5/2007	Hooper	623/14.12
7,955,393	B2 *	6/2011	Hawkins	623/20.14	2007/0129808	A1 *	6/2007	Justin et al.	623/20.15
7,963,996	B2 *	6/2011	Saltzman et al.	623/21.18	2007/0173944	A1 *	7/2007	Keller et al.	623/18.11
7,976,578	B2 *	7/2011	Marvel	623/14.12	2007/0173947	A1 *	7/2007	Ratron et al.	623/21.18
8,002,841	B2 *	8/2011	Hasselman	623/21.18	2007/0299533	A1 *	12/2007	Reiley	623/21.18
8,003,709	B2	8/2011	Shen et al.		2008/0015703	A1 *	1/2008	Casey	623/17.16
8,008,365	B2	8/2011	Shen et al.		2008/0046082	A1 *	2/2008	Lee	623/17.16
8,016,884	B2 *	9/2011	Shterling et al.	623/14.12	2008/0086210	A1 *	4/2008	Fox	623/14.12
8,076,387	B2	12/2011	Muratoglu et al.		2008/0097606	A1 *	4/2008	Cragg et al.	623/14.12
8,092,465	B2 *	1/2012	Metzger et al.	606/96	2008/0097617	A1 *	4/2008	Fellinger et al.	623/21.18
8,100,979	B2 *	1/2012	Felt et al.	623/17.16	2008/0103603	A1 *	5/2008	Hintermann	623/20.32
8,133,234	B2 *	3/2012	Meridew et al.	606/91	2008/0133018	A1	6/2008	Salovey et al.	
8,187,660	B2	5/2012	Lawrynowicz et al.		2008/0195216	A1 *	8/2008	Philipp	623/18.11
					2008/0195233	A1 *	8/2008	Ferrari et al.	623/47
					2008/0208346	A1 *	8/2008	Schwartz	623/17.17
					2008/0234820	A1 *	9/2008	Felt et al.	623/14.12
					2009/0048687	A1 *	2/2009	Tornier et al.	623/47

(56)

References Cited

U.S. PATENT DOCUMENTS

- 2009/0054992 A1* 2/2009 Landes et al. 623/21.18
 2009/0082875 A1* 3/2009 Long 623/21.18
 2009/0088846 A1* 4/2009 Myung et al. 623/14.12
 2009/0118830 A1* 5/2009 Fell 623/14.12
 2009/0138096 A1* 5/2009 Myerson et al. 623/54
 2009/0182377 A1* 7/2009 Petersen 606/247
 2009/0182433 A1* 7/2009 Reiley et al. 623/18.11
 2009/0187252 A1* 7/2009 Howald et al. 623/22.15
 2009/0198341 A1* 8/2009 Choi et al. 623/21.18
 2009/0226068 A1* 9/2009 Fitz et al. 382/131
 2009/0240338 A1* 9/2009 Reiley 623/21.18
 2009/0259314 A1* 10/2009 Linder-Ganz et al. 623/14.12
 2009/0306778 A1* 12/2009 Marvel 623/14.12
 2009/0317767 A1 12/2009 Burger et al.
 2009/0326659 A1 12/2009 Muratoglu et al.
 2010/0057215 A1* 3/2010 Graham 623/21.15
 2010/0057216 A1* 3/2010 Gannoe et al. 623/21.18
 2010/0168859 A1* 7/2010 Wardlaw 623/17.12
 2010/0174376 A1* 7/2010 Lang 623/18.11
 2010/0198355 A1* 8/2010 Kofoed et al. 623/21.18
 2010/0204799 A1* 8/2010 Keller et al. 623/18.11
 2010/0262251 A1 10/2010 Muratoglu et al.
 2010/0298945 A1 11/2010 Schroeder et al.
 2010/0312348 A1 12/2010 Wang et al.
 2010/0312353 A1* 12/2010 Howald et al. 623/23.12
 2010/0318088 A1* 12/2010 Warne et al. 606/87
 2011/0004305 A1* 1/2011 Jansson et al. 623/14.12
 2011/0004315 A1 1/2011 Muratoglu et al.
 2011/0022089 A1* 1/2011 Assell et al. 606/247
 2011/0029094 A1* 2/2011 Hogendijk et al. 623/21.12
 2011/0035012 A1* 2/2011 Linares 623/18.11
 2011/0035019 A1 2/2011 Goswami et al.
 2011/0060366 A1* 3/2011 Heim et al. 606/247
 2011/0066243 A1* 3/2011 Rivin et al. 623/14.12
 2011/0093073 A1* 4/2011 Gatt et al. 623/14.12
 2011/0098746 A1* 4/2011 Peterson et al. 606/249
 2011/0098816 A1* 4/2011 Jacob et al. 623/17.11
 2011/0144757 A1* 6/2011 Linares 623/18.11
 2011/0208317 A1* 8/2011 Feldman 623/21.18
 2011/0257753 A1 10/2011 Gordon et al.
 2011/0272862 A1 11/2011 Schroeder et al.
 2011/0288642 A1* 11/2011 Forsell 623/14.12
 2011/0288643 A1* 11/2011 Linder-Ganz et al. 623/14.12
 2011/0320005 A1* 12/2011 Rydell et al. 623/21.18
 2012/0004734 A1 1/2012 Reiley
 2012/0010718 A1 1/2012 Still
 2012/0010719 A1 1/2012 Reiley
 2012/0046753 A1 2/2012 Cook et al.
 2012/0089232 A1 4/2012 Choi et al.
 2012/0109334 A1* 5/2012 Forsell 623/23.14
 2012/0116531 A1* 5/2012 Forsell 623/23.11
 2012/0185050 A1* 7/2012 Schwartz 623/17.17
 2012/0191211 A1 7/2012 Drozd
 2012/0209382 A1* 8/2012 Forsell 623/14.12
 2012/0232575 A1* 9/2012 Wirtel et al. 606/192
 2012/0232657 A1* 9/2012 Myung et al. 623/14.12
 2012/0245701 A1* 9/2012 Zak et al. 623/21.18
 2012/0310244 A1* 12/2012 Blain et al. 606/79
 2012/0316645 A1* 12/2012 Grotz 623/14.13
 2013/0030542 A1* 1/2013 Grotz 623/20.35
 2013/0073050 A1 3/2013 McEntire et al.
 2013/0144389 A1* 6/2013 Bonutti 623/17.16
 2013/0158658 A1* 6/2013 Hayzlett 623/8
 2013/0204386 A1* 8/2013 Sanders et al. 623/21.18
 2013/0245773 A1 9/2013 Muratoglu et al.
 2013/0245803 A1* 9/2013 Lang 700/98
 2013/0297034 A1* 11/2013 Reiley 623/21.18
 2013/0304224 A1* 11/2013 Schmidt et al. 623/21.18
 2013/0310943 A1* 11/2013 McCormack et al. 623/17.16
 2013/0325009 A1* 12/2013 Duggal et al. 606/64
 2014/0018925 A1* 1/2014 Schwartz 623/17.17
 2014/0018931 A1* 1/2014 Gillard et al. 623/21.18
 2014/0046450 A1* 2/2014 Kellar et al. 623/18.11
 2014/0074245 A1* 3/2014 Shohat et al. 623/19.13

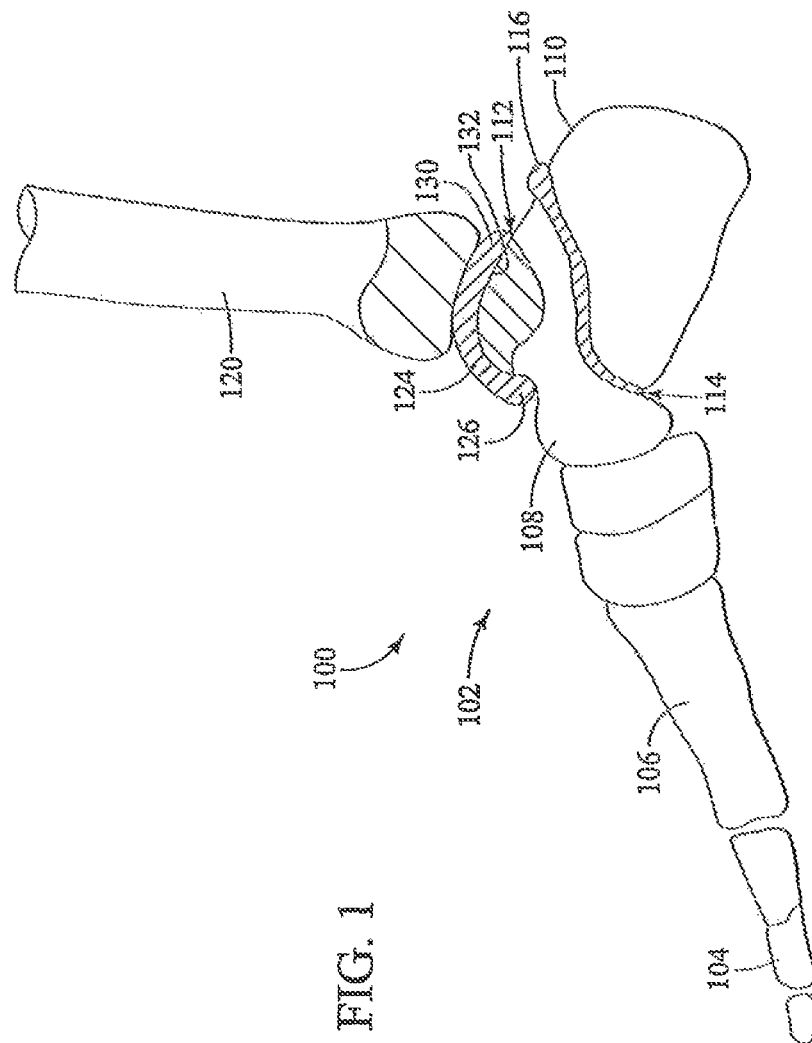
FOREIGN PATENT DOCUMENTS

- WO 98/20939 A2 5/1998
 WO 02/17821 A2 3/2002
 WO 03/053278 A2 7/2003
 WO 03/061522 A2 7/2003
 WO 2004/006811 A2 1/2004

OTHER PUBLICATIONS

Brown, Roger, Handbook of Polymer Testing: Physical Methods, CRC Press, 1999, ISBN: 978-0824701710.

* cited by examiner



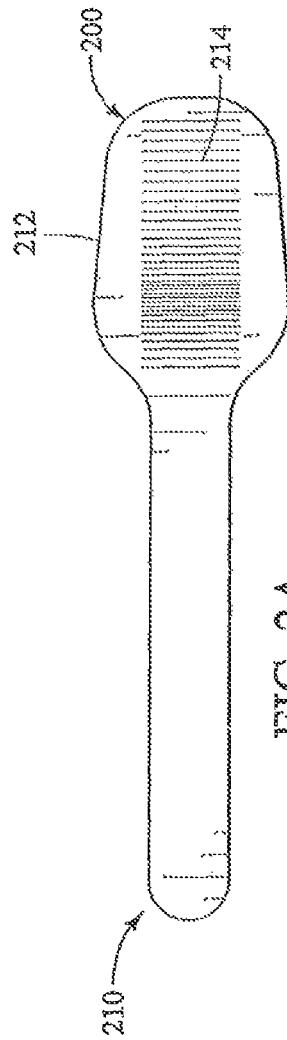


FIG. 2A

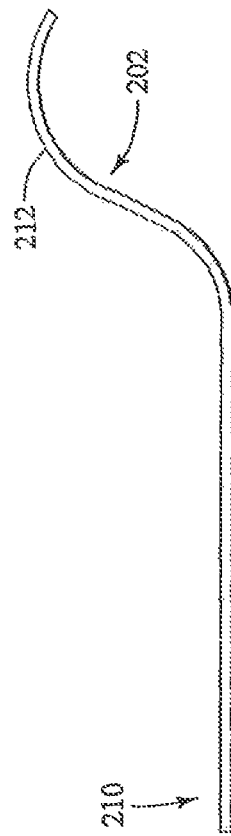


FIG. 2B

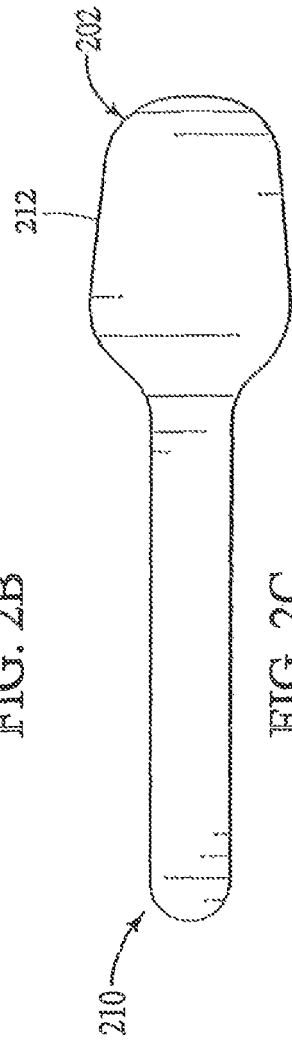


FIG. 2C

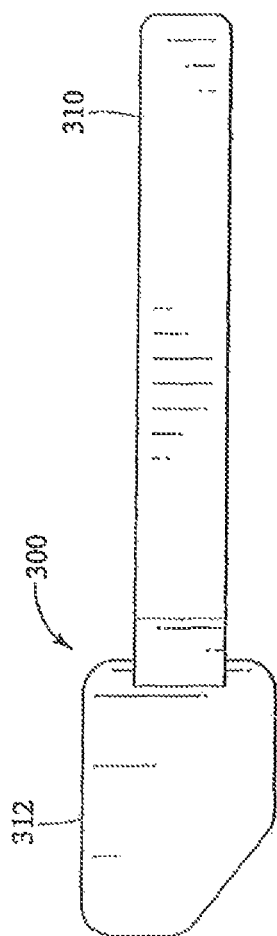


FIG. 3A

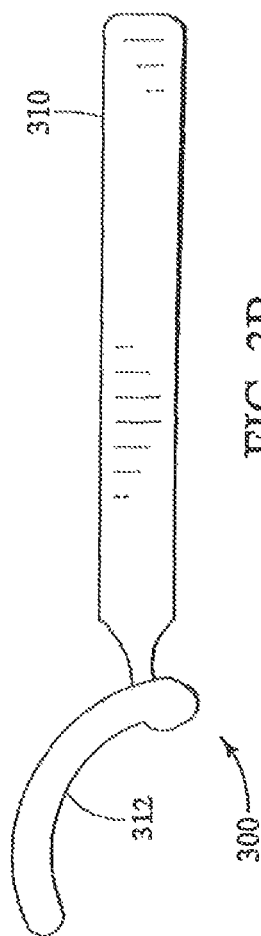


FIG. 3B

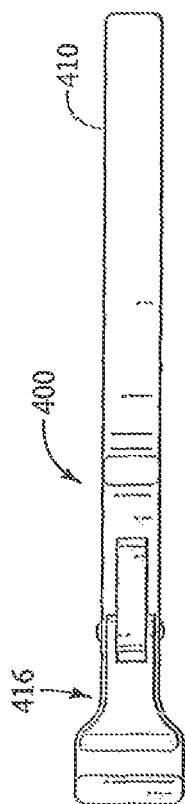


FIG. 4A

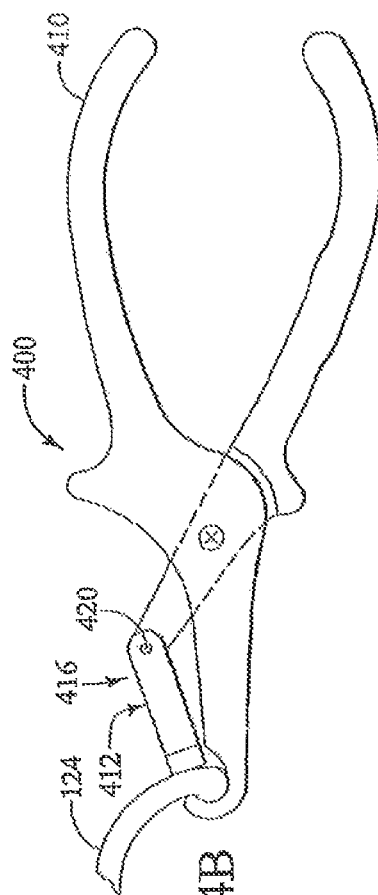


FIG. 4B

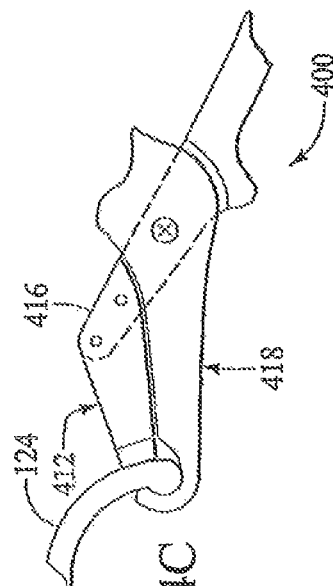


FIG. 4C

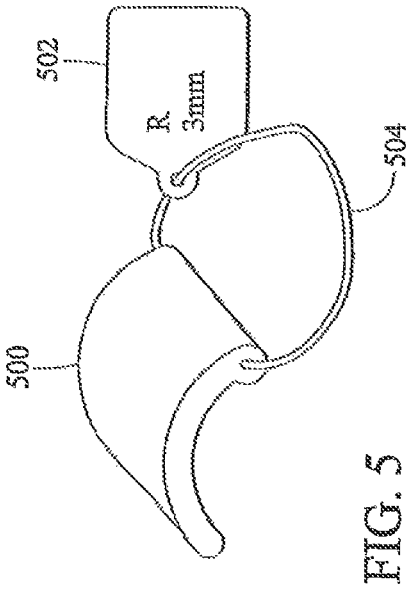
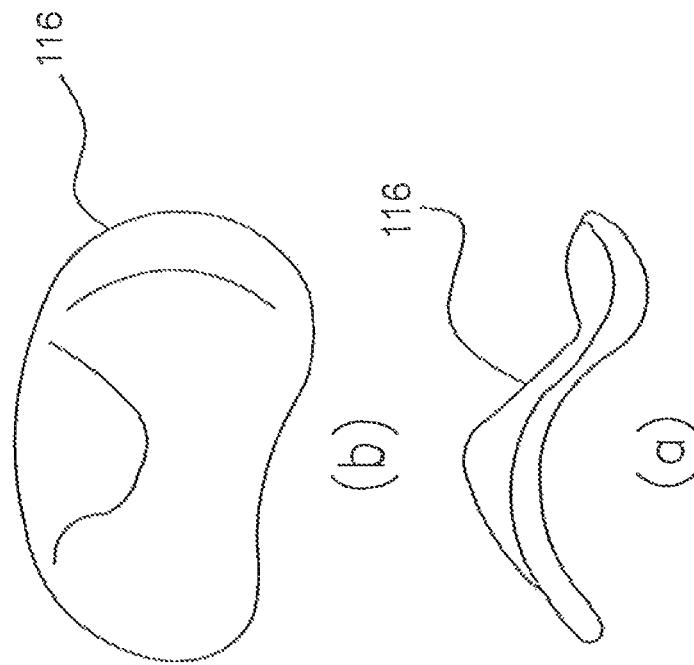


FIG. 5



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SYSTEM AND METHOD FOR ANKLE ARTHROPLASTY

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 10/562,648 filed May 2, 2006, now abandoned, which is a national phase entry under 35 U.S.C. §371 of International Application No. PCT/US2004/020456 filed Jun. 25, 2004, which claims priority from U.S. Provisional Patent Application No. 60/483,499 filed Jun. 27, 2003.

TECHNICAL FIELD

In one aspect, this invention relates to biomaterials for implantation and use within the body. In yet another aspect, this invention further relates to the field of orthopedic implants and prostheses, and more particularly, for implantable materials for use in orthopedic joints.

BACKGROUND OF THE INVENTION

Applicant has previously described, inter alia, prosthetic implants formed of biomaterials that can be delivered and finally cured in situ, and/or that can be partially or fully prepared ex vivo, for implantation into the body, e.g., using minimally invasive techniques. See for instance, U.S. Pat. Nos. 5,556,429; 5,795,353; 6,140,452; 6,306,177; and 6,652,587, as well as US Application Publication Nos. US-2002-0156531; US-2002-0127264; US-2002-0183850; and US-2004-0107000, and International applications having Publication Nos. WO 95/30388; WO 98/20939; WO 02/17821; WO 03/053278; WO 03/061522, and WO 2004/006811 (the disclosures of each of which are incorporated herein by reference).

In spite of developments to date, there remains a need for a joint prosthesis system that provides an optimal combination of properties such as ease of preparation and use, and performance within the body, and particularly for use in joints other than the knee.

SUMMARY OF THE INVENTION

The present invention provides an interpositional arthroplasty system for use in repairing ginglymus joints such as the joints of the ankle. In some preferred embodiments, the system includes an implant designed to be positioned in the tibiotalar (true ankle joint) and/or in the subtalar joint. The implant can comprise one or more biomaterials such as polymers, ceramics, and/or metals, including combinations thereof.

In a preferred embodiment, the invention provides a tibiotalar implant that provides a first major surface adapted to be positioned against a tibia and a second major surface adapted to be positioned against a talus. In a further preferred embodiment, the implant includes one or more structures adapted to improve retention of the implant within the joint site, e.g., by means of an integral bead shaped structure proximate its anterior side adapted to cap and thereby engage the neck of the talus.

In other preferred embodiments, the invention provides a polymeric ankle implant that provides a first major surface adapted to be positioned against a talus and a second major surface adapted to be positioned against the calcaneus bone. In a further embodiment, the implant includes one or more structures adapted to improve retention of the implant within

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the joint site, e.g. by a shape that conforms to the calcaneus, posterior lip, and/or anterior lip. Such an implant can be useful for correcting various deformities of an ankle, such as creating space between bones in the foot to reduce bone on bone impingement, as well as increasing articulation of a joint.

Some embodiments of the system can also include one or more components and one or more related devices, in the form of a kit that can be used to provide or perform some or all of the steps of preparing the joint to receive an implant, determining an appropriate implant size for a particular joint, determining an appropriate implant thickness and/or angle, inserting the implant into the joint, and/or seeming the implant to a desired extent. One or more of the various components and devices, including optionally one or more implants themselves, can be provided or packaged separately or in varying desired combinations and subcombinations to provide a kit of this invention. Further, the invention also includes a method of repairing a ginglymus joint, as well as a ginglymus joint that includes an implant of this invention.

In preferred embodiments, the invention provides a prosthetic device for implantation into an ankle joint space within the body of a mammal, the device comprising a composite or monolith structure fabricated from a biocompatible, biodegradable material that is adapted to be inserted into the joint compartment. More preferably, the implanted device is substantially free of anchoring portions that need to be attached to the bone, cartilage, ligaments or other tissue, yet by its design is capable of being used with minimal translation, rotation, or other undesired movement or dislocation within or from the joint space. The stability of the device within the joint space is provided, in whole or in part, by the fixation/congruency of the device to the one or the other, and generally the relatively less mobile, of the two joint members.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a side view of a foot and ankle region showing implants in accordance with an embodiment of the present invention.

FIG. 2(a) is a top view of a tool useful for preparing a joint to receive an implant in accordance with an embodiment of the present invention.

FIG. 2(b) is a side view of a tool useful for preparing a joint to receive an implant in accordance with an embodiment of the present invention.

FIG. 2(c) is a bottom view of a tool useful for preparing a joint to receive an implant in accordance with an embodiment of the present invention.

FIG. 3(a) is a top view of a sizing tool in accordance with an embodiment of the present invention.

FIG. 3(b) is a side view of a sizing tool in accordance with an embodiment of the present invention.

FIG. 4(a) is a top view of a gripping tool in accordance with an embodiment of the present invention.

FIG. 4(b) is a side view of a gripping tool in accordance with an embodiment of the present invention.

FIG. 4(c) is a side view of a gripping tool in accordance with an alternate embodiment of the present invention.

FIG. 5 is a perspective view of an implant template in accordance with an embodiment of the present invention.

FIG. 6(a) is a side view of an implant in accordance with an embodiment of the present invention.

FIG. 6(b) is a top view of an implant in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

A preferred embodiment will be described with reference to the figures, where FIG. 1 is a side view of a foot 100

including a plurality of bones **102**. The bones of foot **100** include a first phalanges **104**, a metatarsal bone **106**, a talus **108**, and calcaneus **110**. A tibia **120** is also shown in FIG. 1. As shown in FIG. 1, the tibia **120** and talus **108** form a tibiotalar joint **112** (sometimes referred to as a true ankle joint or TAJ). The tibiotalar joint **112** is responsible for up and down motion of the foot. The talus **108** and calcaneus **110** form a subtalar joint **114**. The subtalar joint **114** allows for side to side motion of the foot.

In the embodiment of FIG. 1 a tibiotalus implant **124** is disposed between tibia **120** and talus **108**. The tibiotalus implant **124** can be useful for treating arthritic joints, replacing natural cartilage, and/or providing a separation between the tibia **120** and talus **108** to reduce bone on bone contact during articulation. The tibiotalus implant **124** can have a first major surface **130** useful for positioning against the tibia **120**. The first surface **130** can be adapted to provide an articulating surface for articulation of the tibia **120**. The tibiotalus implant can also have a second major surface **132** adapted for positioning against the talus **108**. The second surface **132** can be useful for providing a cushioning surface and/or congruency with the talus **108**. In such embodiments, the tibiotalar implant **124** can be adapted to provide a combination of desirable wear resistance, congruency, and cushioning properties.

The tibiotalus implant **124** can be provided with means for stabilizing (e.g., fixing) the implant **124** within the joint, wherein the means for stabilizing provides for less motion of the implant relative to the talus **108** than the tibia **120**. With reference to FIG. 1, it will be appreciated that an exemplary means for stabilization means includes a tibiotalus implant **124** that has a bead shaped structure **126** proximate its anterior side that engages the neck of the talus **108** to reduce the likelihood of anterior and posterior movement during articulation. Of course, other stabilization means can be provided to relatively fix the tibiotalar implant **124** to the talus **108**.

The implant **124** can comprise any shape or size that is therapeutically useful. In some embodiments, the implant **124** may be between about 1 mm and 7 mm thick. In a preferred embodiment, the implant **124** is between about 2 mm and 3 mm thick. The implant **124** can also be sized to substantially cover the surface of the top portion of the talus **108**. In such embodiments, the implant **124** can be about 40 mm to 50 mm in length.

Also in the embodiment of FIG. 1, a second implant **116** is disposed between talus **108** and calcaneus **120**. In some embodiments, talus-calcaneus implant **116** can be relatively fixed to calcaneus **110** and allow talus **108** to articulate against it. As shown in FIGS. 6(a) and (b) implant **116** can contain an S-shaped side cross-section useful for following the contour of the calcaneus **110**. Further, implant **116** can contain a posterior lip and/or a anterior lip, each of which are useful for engaging the calcaneus **120** to increase stabilization.

The implant **116** can comprise any shape or size that is therapeutically useful. In some embodiments, implant **116** is between about 2 mm and 5 mm thick. In some preferred embodiments, implant **116** is between about 2.5 mm and 3.5 mm thick. Implant **116** can be sized to substantially cover the top surface of the calcaneus **120**. For example, the implant **116** can be about 35 mm to 45 mm in length.

Some embodiments of the system can also include one or more devices in the form of a kit that can be used to provide or perform some or all of the steps of preparing the joint to receive an implant, determining an appropriate implant size for a particular joint, determining an appropriate implant thickness and/or angle, inserting the implant into the joint,

and/or securing the implant to a desired extent. One or more of the various components and devices, including optionally one or more implants themselves, can be provided or packaged separately or in varying desired combinations and sub-combinations to provide a kit of this invention.

In some embodiments, at least one tool is provided for preparing the joint to receive an implant. Such a tool can comprise a tibial smoother **200** and/or a talus smoother **202** as shown in FIGS. 2(a)-(c). Both the tibial smoother **200** and the talus smoother **202** can be provided with a proximate end **210** useful for manual or motorized manipulation and a smoothing end **212** useful for smoothing the surface of a bone. The smoothing end **212** can be provided with any structure or feature that allows it to adequately remove osteophytes, cartilage and other deposits to smooth the surface, of a bone, such as grit portion **214**. In some embodiments, smoothing end **212** is fenestrated. Such embodiments are useful for smoothing the tibia and talus simultaneously, as well as for providing self-cleaning properties by allowing debris to pass between the superior and anterior sides. Grit portion **214** can be relatively courser for removing larger osteophytes or can be relatively finer for smoothing small osteophytes and finer finishing of the bone surface. Smoother **200** can also be universal in its orientation, permitting it to be used smoothing bone in both the right and left ankles.

In some embodiments, at least one sizing tool for determining an appropriate implant thickness and/or angle is provided. Such a tool can comprise an implant sizer **300** as shown in FIGS. 3(a) and (b). Sizing tool **300** can include proximate end **310** useful for manual manipulation and a sizing end **312** useful for inserting into the body to determine an appropriate implant size. As shown in FIGS. 3(a) and (b), the sizing end **312** can be shaped substantially as an implant. One or more sizing tools **300** can be provided in the form of a kit, with each tool **300** having an identifiable shape, thickness, or angle. In some embodiments, sizing tool **300** is provided with means for adjusting its thickness, such as a track with one or more components that can be locked in to increase thickness.

In some embodiments, a tool is provided for inserting an implant into a joint and or securing the implant to a desired extent. Such a tool can comprise an implant gripper **400** as shown in FIGS. 4(a)-(c). Gripper **400** can be provided with a proximate end **410** useful for manual manipulation and an gripping end **412** useful for gripping and retaining an implant **124** for placement into a body. Gripping end **412** can include a top arm **416** and a bottom arm **418** useful for gripping and retaining an implant **124**. As shown in FIG. 4(b), top arm **416** can include a hinge **420** useful for providing top arm **416** with a lower profile when releasing implant **124**. Other embodiments, such as the one shown in FIG. 4(c), do not include a hinge **420**.

The present invention can also include one or more implant templates **500**, as shown in FIG. 5. Implant template **500** is useful for determining the proper implant thickness and/or angle need to match physiological values. Implant template **500** may be provided in a variety of thicknesses and shapes, e.g. shapes useful for the right and left ankles. A marker, such as a dog tag **502**, can be provided to list this information. In some embodiments, implant template **500** can be inserted with gripper **400**. A band, e.g. a chain **504** can be provided to remove the implant template **500** from the joint. In some embodiments, chain **504** can also retain dog tag **502**. Of course, the implant itself may be provided with a marker, such as a dog tag **502** and a band **504**, which can be removed at the time of implantation.

The tools described above can be constructed of any suitable material. For example, the tools can be constructed of

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stainless steel, ceramic, and/or polymeric materials. Embodiments constructed at least partially of stainless steel can be relatively more suitable for providing a reusable tool, and embodiments constructed at least partially of a polymer can be relatively more suitable for providing a disposable tool. Further, all of the tools above can be shaped to provide an ergonomic fit for the user. Some embodiments provide a universal tool that can be adapted, e.g., configured, to provide an ergonomic fit for both left and right hands.

In one exemplary ankle surgery method in accordance with the present invention, an incision is made in the front of the foot, anterior to the tibiotalar joint **112**. The tibiotalar implant **124** is inserted into the space between the two bones. In embodiments provided with a bead shaped structure **126**, the head shaped structure **126** is placed in contact with the neck of the talus **108** to reduce the likelihood of anterior and posterior movement during articulation. The implant can be further restrained by adjacent soft tissue. The incision is finally sutured closed.

In one exemplary ankle surgery method in accordance with the present invention, an incision is made in the lateral side of the foot. The subtalar implant **116** is inserted into the space between the talus **108** and the calcaneus **110**. In embodiments provided with a posterior and/or anterior lip, such lip is placed in contact with the calcaneus **110** to reduce the likelihood of anterior and posterior movement during articulation. The implant can be further restrained by adjacent soft tissue. The incision is finally sutured closed.

The methods of repairing the joints described above can also include the steps of preparing a joint to receive an implant, determining an appropriate implant size for a particular joint, determining an appropriate implant thickness, inserting the implant into the joint, and/or securing the implant to a desired extent. In some embodiments, these steps are performed with the use of one or more of the tools or apparatus described above.

In some embodiments, implants **124** and **116** may be provided with means to confirm their post-operative position. For example, implants **124** and **116** can be radio-opaque. In such embodiments, a radio-opaque material, such as tungsten, can be provided within the implant in one or more locations. The implant location can then be determined using radio-opacity techniques known in the art.

The biomaterial can be prepared from any suitable material. Generally, a material is suitable if it has appropriate biostability, biodegradability and biocompatibility characteristics. Typically, the materials include polymeric materials, having an optimal combination of such properties as biostability, biocompatibility, physical strength and durability, and compatibility with other components (and/or biomaterials) used in the assembly of a final composite.

Examples of polymeric materials that may be suitable in some applications, either alone or in combination, include polyurethane, available from Polymer Technology Group Incorporated under the names BionateTM, BiospanTM and BlasthaneTM, available from Dow Chemical Company under the name PellethaneTM, and available from Bayer Corp. under the names BayflexTM, TexinTM and DesniopanTM; ABS, available from GE Plastics under the name CyclolacTM, and available from Dow Chemical Company under the name MagrunnTM; SAN, available from Bayer Plastics under the name LustranTM; Acetal, available from Dupont under the name DelrinTM, and available from Ticona GmbH and/or Ticona LLC (Ticona) under the name CelconTM; polycarbonate, available from GE Plastics under the name LexanTM, and available from Bayer Corp. under the name MakrolonTM; polyethylene, available from Huntsman LLC, and available

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from Ticona under the names GUR 1020TM and GUR 1050TM; polypropylenes, available from Solvay Engineered Polymers, Inc. under the name DextflexTM; aromatic polyesters, available from Ticona; polyetherimide (PEI), and available from GE Plastics under the name UltemTM; polyamideimide (PAI), available from DSM E Products under the name TorlonTM; polyphenylene sulfide, available from Chevron Phillips Chemical Company LP under the name RytonTM; polyester, available from Dupont under the name DacronTM; polyester thermoset, available from Ashland Specialty Chemical Company under the name AropolTM; polyureas; hydrogels, available from Hydromer Inc.; liquid crystal polymer, available from Ticona under the name VectraTM; polysiloxanes, available from Nusil Technologies, Inc.; polyacrylates, available from Rohm & Haas under the name PlexiglasTM; epoxies, available from Ciba Specialty Chemicals; polyimides, available from Dupont under the names KaptonTM and VespelTM; polysulfones, available from BP Amoco Chemicals under the name UdelTM, and available from BASF Corporation under the name UltrasonTM; PEAK/PEEK, available from Victrex under the name Victrex PEAKTM; as well as biopolymers, such as collagen or collagen-based materials, chitosan and similar polysaccharides, and combinations thereof. Of course, any of the materials suitable for use in a composite or single biomaterial implant may be structurally enhanced with fillers, fibers, meshes or other structurally enhancing means.

The present provides a biomaterial having an improved combination of properties for the preparation, storage, implantation and long term use of medical implants. The improved properties correspond well for the preparation and use of an implant having both weight bearing and/or articulating functions, and preferably in the form of an implant for interpositional arthroplasty.

In turn, a preferred biomaterial of this invention provides an optimal combination of properties relating to wear resistance, congruence, and cushioning while meeting or exceeding requirements for biocompatibility, all in a manner that serves to reduce the coefficient of friction at the major motion interface.

Wear resistance can be assessed by determining parameters such as DIN abrasion and flexural stress strain fatigue resistance. A preferred implant will have sufficient wear resistance to avoid the generation of clinically significant particulate debris over the course of the implant's use.

Congruence can be assessed by determining parameters such as tensile modulus compressive modulus, and hardness, to determine the manner and extent to which the implant will conform itself to possible other components of the implant itself and/or to bone or surrounding tissue.

Cushioning can be assessed by determining such parameters as hardness, compressive modulus, and tensile modulus, to determine the elastomeric nature of the material, and in turn, its suitability for use in a weight bearing joint. More elastomeric materials will generally provide greater comfort in weight bearing applications, particularly if the other physical properties can be maintained.

Applicant has discovered that improved wear resistance, congruence, and/or cushioning toughness can be achieved without undue effect on other desired properties, such as abrasion, hardness, specific gravity, tear resistance, tensile strength, ultimate elongation, and biocompatibility. Moreover, Applicant has discovered that such properties can themselves be provided in varying forms, as between first and second biomaterials of a composite of the present invention.

A polymeric biomaterial of this invention can be prepared using any suitable means, including by curing the polymer ex

vivo. The composition can be used in any suitable combination with other materials, including other compositions of the same or similar nature, as well as other materials such as natural or synthetic polymers, metals, ceramics, and the like.

The invention further provides a method of preparing the composition, a method of using the composition, implants that comprise the composition, as well as methods of preparing and using such implants.

The biomaterial used in this invention preferably includes polyurethane components that are reacted ex vivo to form a polyurethane ("PU"). The formed PU, in turn, includes both hard and soft segments. The hard segments are typically comprised of stiffer oligourethane units formed from diisocyanate and chain extender, while the soft segments are typically comprised of one or more flexible polyol units. These two types of segments will generally phase separate to form hard and soft segment domains, since they tend to be incompatible with one another. Those skilled in the relevant art, given the present teaching, will appreciate the manner in which the relative amounts of the hard and soft segments in the formed polyurethane, as well as the degree of phase segregation, can have a significant impact on the final physical and mechanical properties of the polymer. Those skilled in the art will, in turn, appreciate the manner in which such polymer compositions can be manipulated to produce cured and curing polymers with desired combination of properties within the scope of this invention.

The hard segments of the polymer can be formed by a reaction between the diisocyanate or multifunctional isocyanate and chain extender. Some examples of suitable isocyanates for preparation of the hard segment of this invention include aromatic diisocyanates and their polymeric form or mixtures of isomers or combinations thereof, such as toluene diisocyanates, naphthalene diisocyanates, phenylene diisocyanates, xylylene diisocyanates, and diphenylmethane diisocyanates, and other aromatic polyisocyanates known in the art. Other examples of suitable polyisocyanates for preparation of the hard segment of this invention include aliphatic and cycloaliphatic isocyanates and their polymers or mixtures or combinations thereof, such as cyclohexane diisocyanates, cyclohexyl-bis methylene diisocyanates, isophorone diisocyanates and hexamethylene diisocyanates and other aliphatic polyisocyanates. Combinations of aromatic and aliphatic or arylakyl diisocyanates can also be used.

The isocyanate component can be provided in any suitable form, examples of which include 2,4'-diphenylmethane diisocyanate, 4,4'-diphenylmethane diisocyanate, and mixtures or combinations of these isomers, optionally together with small quantities of 2,2'-diphenylmethane diisocyanate (typical of commercially available diphenylmethane diisocyanates). Other examples include aromatic polyisocyanates and their mixtures or combinations, such as are derived from phosgenation of the condensation product of aniline and formaldehyde. It is suitable to use an isocyanate that has low volatility, such as diphenylmethane diisocyanate, rather than more volatile materials such as toluene diisocyanate. An example of a particularly suitable isocyanate component is the 4,4'-diphenylmethane diisocyanate ("MDI"). Alternatively, it can be provided in liquid form as a combination of 2,2', 2,4'- and 4,4'-isomers of MDI. In a preferred embodiment, the isocyanate is MDI and even more preferably 4,4'-diphenylmethane diisocyanate.

In one embodiment of the invention, the isocyanate is 4,4'-diphenylmethane, diisocyanate (as available from Bayer under the tradename Mondur M), from preferably about 20 to 60 weight percent, more preferably from about 30 to 50 weight percent. The actual amount of isocyanate used should

be considered in combination with other ingredients and processing parameters, particularly including the amount of chain extender (such as butanediol (BDO)) used, since the combination typically determines the hard segment component, and in turn hardness, of the corresponding cured polymer. Hardness correlates in a generally proportional fashion with the combined weights of MDI and BDO, such that compositions having between 30 and 60 total weight percent (MDI+BDO) are generally useful, with those compositions having between about 50 to about 60 total weight percent being somewhat harder, and particularly useful for either the first (femoral contacting) biomaterial and surface of a composite implant or for implants having a single biomaterial providing both first and second surfaces. By contrast, compositions having between about 40 to about 50 total weight percent are somewhat more congruent and cushioning, though less wear resistant, and therefore are preferred for use as the second biomaterial, e.g., tibial contacting surface, of a composite implant as described herein.

Some examples of chain extenders for preparation of the hard segment of this invention include, but are not limited to, short chain diols or triols and their mixtures or combinations thereof, such as 1,4-butane diol, 2-methyl-1,3-propane diol, 1,3-propane-diol ethylene glycol, diethylene glycol, glycerol, tri-methylpropane, cyclohexane dimethanol, triethanol amine, and methyldiethanol amine. Other examples of chain extenders for preparation of the hard segment of this invention include, but are not limited to, short chain diamines and their mixtures or combinations thereof, such as dianiline, toluene diamine, cyclohexyl diamine, and other short chain diamines known in the art.

The soft segment consists of urethane terminated polyol moieties, which are formed by a reaction between the polyisocyanate or diisocyanate or polymeric diisocyanate and polyol. Examples of suitable diisocyanates are denoted above. Some examples of polyols for preparation of the soft segment of this invention include but are not limited to polyalkylene oxide ethers derived from the condensation of alkylene oxides (e.g. ethylene oxide, propylene oxide, and blends thereof), as well as tetrahydrofuran based polytetramethylene ether glycols, polycaprolactone diols, polycarbonate diols and polyester diols and combinations thereof. In a preferred embodiment, the polyols are polytetrahydrofuran polyols ("PTHF"), also known as polytetramethylene oxide ("PTMO") or polytetramethylene ether glycols ("PTMEG"). Even more preferably, the use of two or more of PTMO diols with different molecular weights selected from the commercially available group consisting of 250, 650, 1000, 1400, 1800, 2000 and 2900.

Two or more PTMO diols of different molecular weight can be used as a blend or separately, and in an independent fashion as between the different parts of a two part system. The solidification temperature(s) of PTMO diols is generally proportional to their molecular weights. The compatibility of the PTMO diols with such chain extenders as 1,4-butanediol is generally in the reverse proportion to the molecular weight of the diol(s). Therefore the incorporation of the low molecular weight PTMO diols in a "curative" (part B) component of a two part system, and higher molecular weight PTMO diols in the prepolymer (part A) component, can provide a two-part system that can be used at relatively low temperature. In turn, good compatibility of the low molecular weight PTMO diols with such chain extenders as 1,4-butanediol permits the preparation of two part systems with higher (prepolymer to curative) volume ratio. Amine terminated polyethers and/or polycarbonate-based diols can also be used for building of the soft segment.

In one embodiment of the invention, the polyol is polytetramethyleneetherglycol 1000 (as available from E.I. du Pont de Nemours and Co. under the tradename Terathane 1000), preferably from about 0 to 40 weight percent, more preferably from about 10 to 30 weight percent, and perhaps even more preferably from about 22 to 24 weight percent, based on the total weight of the polymer. The polyol disclosed above may be used in combination with polytetramethyleneetherglycol 2000 (as available from E.I. du Pont de Nemours and Co. under the tradename Terathane 2000), preferably from about 0 to 40 weight percent, more preferably from about 10 to 30 weight percent, and perhaps even more preferably from about 17 to 18 weight percent, based on the total weight of the polymer.

In one embodiment, the biomaterial may include a chain extender. For example, the chain extender may be 1,4-butanediol (as available from Sigma Aldrich Corp.), preferably from about 1 to 20 weight percent, more preferably from 5 to 15 weight percent, to perhaps even more preferably from 12 to 13 weight percent, based on the total weight of the polymer.

The polyurethane can be chemically crosslinked, e.g., by the addition of multifunctional or branched OH-terminated crosslinking agents or chain extenders, or multifunctional isocyanates. Some examples of suitable crosslinking agents include, but are not limited to, trimethylol propane ("TMP"), glycerol, hydroxyl terminated polybutadienes, hydroxyl terminated polybutadienes (HOPB), trimer alcohols, Castor oil polyethyleneoxide (PEO), polypropyleneoxide (PPO) and PEO-PPO triols. In a preferred embodiment, HOPB is used as the crosslinking agent.

This chemical crosslinking augments the physical or "virtual" crosslinking of the polymer by hard segment domains that are in the glassy state at the temperature of the application. The optimal level of chemical cross-linking improves the compression set of the material, reduces the amount of the extractable components, and improves the biodegradability of the PU. This can be particularly useful in relatively soft polyurethanes, such as those suitable for the repair of damaged cartilage. Reinforcement by virtual cross-links alone may not generate sufficient strength for in vivo performance in certain applications. Additional cross-linking from the soft segment, potentially generated by the use of higher functional polyols can be used to provide stiffer and less elastomeric materials. In this manner a balancing of hard and soft segments, and their relative contributions to overall properties can be achieved.

In one embodiment, the chemical cross-linking agent is 2-ethyl-2-(hydroxymethyl)-1,3-propanediol (also known as trimethylolpropane, as available from Sigma Aldrich Corp.), preferably from about 0 to 5 weight percent, more preferably from about 0.1 to 1 weight percent, and perhaps even more preferably from about 0.15 to 0.3 weight percent, based on the total weight of the polymer.

Additionally, and optionally, a polymer system of the present invention may contain at least one or more biocompatible catalysts that can assist in controlling the curing process, including the following periods: (1) the cure induction period, and (2) the full curing period of the biomaterial. Together these two periods, including their absolute and relative lengths, and the rate of acceleration or cure within each period, determine the cure kinetics or profile for the composition. In some embodiments, however, a catalyst is not included. For instance embodiments in which the biomaterial is heated in the course of curing, such as in a heated mold in the manner described herein, can be performed without the use of a catalyst.

Some examples of suitable catalysts for preparation of the formed PU of this invention include, but are not limited to, tin and tertiary amine compounds or combinations thereof such as dibutyl tin dilaurate (DBTDL), and tin or mixed tin catalysts including those available under the tradenames "Cotin 222", "Fomrez UL-22" (Crompton Corp.), "dabco" (a triethylene diamine from Sigma-Aldrich), stannous octanoate, trimethyl amine, and triethyl amine.

In one embodiment of the invention; the catalyst is bis-(dodecylthio)-dimethylstannane (available from Crompton Corp. as Fomrez catalyst UL-22), preferably from about 0 to 2 weight percent, more preferably from about 0 to 1 weight percent, and perhaps most preferably from 0.0009 to 0.002 weight percent, based on the total weight of the polymer.

Further, a polymer stabilizer additive useful, for protecting the polymer from oxidation may be included. In one embodiment of the invention, the additive is pentaerythritol tetrakis (3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate (available from Ciba Specialty Chemical, Inc. as Irganox 1010), preferably from about 0 to 5 weight percent, more preferably about 0.1 to 1 weight percent, and perhaps even more preferably about 0.35 to 0.5 weight percent, based on the total weight of the polymer.

Optionally, other ingredients or additives can be included, for instance, a reactive polymer additive can be included from the group consisting of hydroxyl- or amine-terminated compounds selected from the group consisting of polybutadiene, polyisoprene, polyisobutylene, silicones, polyethylene-propylenediene, copolymers of butadiene with acrylonitrile, copolymers of butadiene with styrene, copolymers of isoprene with acrylonitrile, copolymers of isoprene with styrene, and mixtures of the above. Other additives may also be optionally provided. For example, catalysts such as Dabco, antioxidants such as vitamin E, hydrophobic additives such as hydroxyl-terminated polybutadiene, and dye green GLS, singularly or in combination, may be included in the polymer formulation.

Suitable compositions for use in the present invention are those polymeric materials that provide an optimal combination of properties relating to their manufacture, application, and in vivo use. In the uncured state, such properties include component miscibility or compatibility, processability, and the ability to be adequately sterilized or aseptically processed and stored. While the composition is curing, suitable materials exhibit an optimal combination of cure kinetics and exotherm. In the cured state, suitable compositions exhibit an optimal combination of such properties as abrasion, hardness, specific gravity, tear resistance, tensile strength, ultimate elongation, and biocompatibility.

The composition of the present invention provides a polyurethane that can be prepared ex vivo. Particularly when formed ex vivo, products incorporating the composition of this invention may be made in advance of their use, on a commercial scale, and under stringent conditions.

Polymeric biomaterials of this invention, including preferred polyurethanes can be prepared using automated manufacturing processes within the skill of those in the art. A preferred manufacturing method, for instance, includes the use of multichannel dispensing equipment to inject the polymer. Such equipment is well suited to high precision applications, having a variable or fixed number of channels, some have all channels dispensing the same volume while in others the volume can be set by channel, some have all channels dispensing the same fluid, while others allow for different fluids in different channels. The dispensing can be automated repetitive or manual. Suitable devices for metering, mixing and dispensing materials such as urethanes are commercially

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available from a variety of sources, including for instance from Adhesive Systems Technology Corp., 9000 Science Center Drive; New Hope, Minn. 55428.

Furthermore, polymeric biomaterials of this invention may be cured in a heated mild. The mold may receive the contents of the polymeric biomaterial before it is cured. In one embodiment, a permanent enclosed mold is used to form at least a part of the implant. Such a mold may be similar to a standard injection mold and have the ability to withstand large clamping forces. Further, such a mold may include runners and/or vents to allow material to enter and air to exit. Such a mold may be constructed from metals, polymers, ceramics, and/or other suitable materials. The mold may be capable of applying and controlling heat to the biomaterial to accelerate curing time. In some embodiments, the mold may be coated with a release coating agent to facilitate ease of removal of the cured biomaterial from the mold. Examples of suitable release agents include TeflonTM, silicone, fluorinated ethylene propylene (FEP), dichronite, gold, and nickel-Teflon combinations, various types of which are commercially available from a variety of sources, e.g., McLube Division of McGee Industries. In addition, the mold may be provided in two separable parts to further facilitate removal of the cured biomaterial.

Further, time and temperature parameters can be modified in processing to change the characteristics of the implant. A time temperature profile may be selected to achieve certain implant properties. In embodiments formed with a heated mold as described above, those skilled in the art will appreciate the manner in which both the temperature of the mold as well as the time biomaterial is maintained can be adjusted to change the characteristics of the molded implant.

In the embodiment in which an ex vivo curing polymer is used, the present invention preferably provides a biomaterial in the form of a curable polyurethane composition comprising a plurality of parts capable of being at least partially mixed at a time before use, the parts including: (1) a polymer component comprising the reaction product of one or more polyols, and one or more diisocyanates, and (2) a curative component comprising one or more chain extenders, one or more catalysts, and optionally, one or more polyols and/or other optional ingredients.

In some embodiments, long term congruence of the biomaterial is facilitated by its hydration in vivo, permitting the biomaterial to become more pliable, and in turn, facilitate congruence with the tibial plateau. In turn, an increase in hydration and/or changes in temperature can improve the fit and mechanical lock between the implant and the tibial plateau. The biomaterial may be hydrated ex vivo and/or in vivo, both before and after the composition is cured. Preferably, the biomaterial may be further hydrated within the joint site after the composition in order to enhance both conformance and performance of the implant.

Implantable compositions of this invention demonstrate an optimal combination of properties, particularly in terms of their physical/mechanical properties, and biocompatibility. Such performance can be evaluated using procedures commonly accepted for the evaluation of natural tissue, as well as the evaluation of materials and polymers in general, in particular, a preferred composition, in its cured form, exhibits physical and mechanical properties that approximate or exceed those of the natural tissue it is intended to provide or replace. Fully cured polymeric (e.g., polyurethane) biomaterials within the scope of this invention provide an optimal combination of such properties as abrasion, compressive hardness, compressive modulus hardness, specific gravity,

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tear resistance, tensile strength, ultimate elongation, tensile modulus, and biocompatibility.

Physical/Mechanical Properties and Test Methods

Various properties of the composition of this invention can be evaluated for use in quality control, for predicting service performance, to generate design data, to determine compliance with established standards, and on occasion, to investigate failures. See, for instance, Handbook of Polymer Testing: Physical Methods, edited by Roger Brown, Marcel Dekker, Inc., New York, N.Y. (1999), the disclosure of which is incorporated herein by reference. Suitable properties include those dealing with a) mass, density and dimensions, b) processability, c) strength and stiffness (including compressive hardness, compressive modulus; tensile stress-strain, flexural stress-strain, flexibility, and tear tests), c) fatigue and wear (including abrasion resistance and hardness), d) time dependent properties (such as creep, stress relaxation, compression set, tension set), e) effect of temperature (such as thermal expansion, shrinkage, and thermal oxidative aging), f) environmental resistance, and g) and biocompatibility parameters.

Of particular note are those properties that lend themselves to the preparation, delivery and long term use of improved implants having an articulating surface, and preferably for long term weight bearing use.

The preferred property ranges given below are only relevant to certain embodiments of the invention, it will be appreciated by those reasonably skilled in the art that materials having one or more properties outside the scope of the preferred ranges given below are suitable for use with the present invention.

Abrasion values for a polymer can be determined with a rotating cylindrical drum device, known as a DIN abrader. A loaded cylindrical test piece is traversed along an abrasive cloth attached to a rotating drum, and the mass loss is measured after a specified length of travel. Advantages of this device include the use of a test piece small enough to be cut from a product or a comparatively thin sheet and a much reduced risk of abrasive contamination caused by debris or smearing. The result can be expressed with the abrasion resistance index, which is the ratio of the volume loss of a black standard rubber sample to the volume loss of the test sample.

The polymer preferably provides a DIN abrasion value of less than about 70 mm³, more preferably less than about 60 mm³ and most preferably less than about 50 mm³, as determined by ASTM Test Method D5963-96 ("Standard Test Method for Rubber Property Abrasion Resistance Rotary Drum Abrader"). DIN abrasion values of greater than about 70 mm³ tend to exhibit wear rates that are too great for longer term use as articulating surface.

Biomaterial can be formed into standardized (e.g., puck-like) implant shapes and subjected to conditions intended to replicate, while also meet and exceed physiological conditions. Preferred biomaterials of this invention are able to withstand one million cycles (approximately equivalent to 1 year implantation), and more preferably greater than 5 million cycles (approximately equivalent to 5 years) before generating unsuitable debris.

Flexural stress/strain fatigue can be measured in a variety of ways. Using the standardized shape as described above, samples can be compressively loaded in cycles of increasing loads, and the stress strain fatigue can be plotted versus the number of cycles.

As another example, flexural stress/strain fatigue can be determined by a three point bending test, in which a standardized implant sample shape is supported at its anterior and posterior ends. A cyclical load is applied to the sample in an

area substantially between the two supports to provide a deflection of approximately 4 mm, and the total number of cycles until failure is recorded.

Biomaterials formed into implant shapes in accordance with the present invention, under conditions intended to meet and exceed physiological conditions, are preferably able to withstand one million cycles (approximately equivalent to 1 year implantation), and more preferably greater than five million cycles (approximately equivalent to 5 years implantation) in a test similar to the one described above.

Fracture toughness can generally be determined by a number of methods. For example, fracture toughness can be measured by tests similar to ASTM Test Method D5045-99.

Preferably, the polymer provides a peak load fracture toughness of at least about 50 lbs, more preferably more than about 80 lbs, and most preferably more than about 110 lbs. Further, the polymer preferably provides an energy to break fracture toughness of greater than about 15 lb-in, more preferably greater than about 25 lb-in, and most preferably greater than about 30 lb-in. These values may be obtained with tests similar to ASTM Test Method D5045-99.

The term hardness has been applied to scratch resistance and to rebound resilience, but for polymers it is taken to refer to a measure of resistance to indentation. The mode of deformation under an indenter is a mixture of tension, shear, and compression. The indenting force is usually applied in one of the following ways: Application of a constant force, the resultant indentation being measured, measurement of the force required to produce a constant indentation, or use of a spring resulting in variation of the indenting force with depth of indentation.

A biomaterial of this invention preferably provides a hardness value when hydrated of less than about 75 Shore D, more preferably less than about 70 Shore D, and most preferably less than about 60 Shore D, as determined by ASTM Test Method D2240. In some embodiments, hydration of the biomaterial may lower the shore hardness value.

In one method of determining specific gravity, a test piece is provided weighing a minimum of 2.5 grams, which can be of any shape as long as the surfaces are smooth and there are no crevices to trap air. The test piece is weighed in air and then in water using a balance accurate to 1 mg. The test piece can be suspended by means of a very fine filament, the weight of which can be included in the zero adjustment of the balance and its volume in water ignored. The specific gravity is calculated from the difference in measurements.

The polymer preferably provides a specific gravity of about 1 to 2 g/cm³, more preferably about 1 to 1.5 g/cm³, and most preferably about 1.15 to 1.17 g/cm³, as determined by ASTM Test Method D792.

A tear test may be used to measure tear strength. In a tear test, the force is not applied evenly but is concentrated on a deliberate flaw or sharp discontinuity in the sample and the force to produce continuously new surface is measured. This force to start or maintain tearing will depend in a complex manner on the geometry of the test piece and the nature of the discontinuity.

Preferably, a biomaterial of this invention provides a tear strength value in the Die C configuration of greater than about 400 pounds per linear inch (PLI), more preferably greater than about 600 PLI, and most preferably greater than about 800 PLI, and a value in the Die T configuration of preferably greater than about 100 PLI, more preferably greater than about 150 PLI, and most preferably greater than about 250 PLI, as determined by ASTM Test Method D624.

To measure tensile modulus, tensile strength, and ultimate elongation, a test piece of the material is stretched until it

breaks, and the force and elongation at various stages is measured. A tensile machine is used to perform this test. Generally, the basic elements of a tensile machine are grips to hold the test piece, a means of applying a strain (or stress), a force-measuring instrument, and an extensometer.

The polymer preferably provides a tensile modulus at 100% elongation value of about 1,000 to 10,000 psi, more preferably about 2,000 to 5,000 psi, and most preferably about 2,500 to 4,500 psi, as determined by ASTM Test method D412.

The polymer preferably provides a tensile modulus at 200% elongation value of about 1,000 to 10,000 psi, more preferably about 2,000 to 6,000 psi, and most preferably about 2,500 to 5,000 psi, as determined by ASTM Test method D412.

The polymer preferably provides a tensile strength value of greater than about 6,000 psi, more preferably greater than about 6,500 psi, and most preferably greater than about 7,000 psi., as determined by ASTM Test Method D412.

Preferably, the polymer provides an ultimate elongation of greater than about 200%, more preferably greater than about 250%, and most preferably greater than about 300%, as determined by ASTM Test Method D412.

To measure compressive modulus and compressive strength, a sample is again formed in a standardized (e.g., puck) shape and varying compressive loads are applied to the sample in order to develop a corresponding curve. The compressive modulus can be determined from this curve. Compressive strength may be determined by applying increasing loads to a sample until the sample fails.

Preferably, the sample implant provides an compressive modulus of greater than about 4,000 psi, more preferably greater than about 4,500 psi, and most preferably greater than about 5,000 psi, as determined in the manner described above.

Preferably, the sample implant also provides a compressive strength of greater than about 6,000 psi, more preferably greater than about 7,000 psi, and most preferably greater than about 8,000 psi, as determined by a test similar to the one described above.

Water absorption may be determined in a variety of ways. A suitable method for measuring water absorption is to submerge a sample of the test material, with an implant-type geometry, in a saline solution. Once the sample and saline solution reach equilibrium at 37 degrees Celsius, which may take a month or longer, the sample is removed and weighed to determine its water absorption.

Preferably, the polymer provides a water absorption value less than about 5% at 37 C, more preferably less than about 3% at 37 C, and most preferably less than about 2% at 37 C, as determined by a test similar to the one described above.

The medical-grade polyurethane resins were evaluated for biocompatibility in accordance with ISO 10993: Biological Evaluation of Medical Devices and FDA G95-1: Required Biocompatibility Training and Toxicology Profiles for Evaluation of Medical Devices. The biological effects of the resin, such as cytotoxicity, sensitization, genotoxicity, implantation, chronic toxicity, and carcinogenicity, were studied. The tests were conducted in accordance with the FDA Good Laboratory Practice (GLP) Regulation.

The following tests were conducted to determine if the polymer is biocompatible: 1) ISO MEM elution using L-929 mouse fibroblast cells; 2) ISO agarose overlay using L-929 mouse fibroblast cells; 3) ISO acute systemic injection test; 4) ISO intracutaneous reactivity test; 5) ISO guinea pig maximization sensitization test; 6) Material mediated rabbit pyrogen test; 7) in vitro genotoxicology test; and 8) ISO muscle

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implantation study in the rabbit with histology-1 week. The results of the eight selected screening biocompatibility tests above show that the polymer passes all the tests and is considered biocompatible.

In an alternative embodiment, the implant can be provided by any of a series of metals, including titanium, stainless steel, cobalt chrome millithium alloys and tantalum. Other surface materials can include various ceramics and biologic polymers.

Numerous characteristics and advantages of the invention covered by this document have been set forth in the foregoing description. It will be understood, however, that this disclosure is, in many respects, only illustrative. Changes can be made in details, particularly in matters of shape, size and ordering of steps without exceeding the scope of the invention. The invention's scope is, of course; defined in the language in which the appended claims are expressed.

What is claimed is:

1. A monolithic tibiotalar implant for use in arthroplasty repair of ginglymus joints, comprising: a first major surface of the monolithic implant curved for positioning against a tibia and configured to allow the tibia to articulate across the first major surface; a second major surface of the monolithic implant curved for positioning against a talus; and a protrusion proximate to the implant's anterior side sized to engage the neck of the talus, wherein the first and second major surfaces curve only in an anterior-posterior direction, and wherein the first major surface is curved differently than the second major surface such that the first major surface is adapted to be congruent with the tibia and the second major surface is adapted to be congruent with the talus, and wherein the monolithic implant is comprised of a polymeric biomaterial that includes both hard and soft segments to provide at least one of desirable wear resistance, congruency, and cushioning properties.

2. The implant according to claim 1 wherein the monolithic tibiotalar implant has one or more external structures adapted to improve retention of the implant within the joint site.

3. The implant according to claim 2 wherein the protrusion is located on the implant's anterior side.

4. The implant according to claim 1 wherein the implant is comprised of a biomaterial.

5. The implant according to claim 4 wherein the biomaterial is a polyurethane.

6. The implant according to claim 5 wherein the polyurethane is biocompatible with respect to cytotoxicity, sensitization, genotoxicity, chronic toxicity, and carcinogenicity.

7. The implant according to claim 5 wherein the polyurethane has a Shore hardness of at least about 60 D or less.

8. A method of repairing a tibiotalar joint, comprising the steps of providing and implanting an implant according to claim 1, the implant being inserted through an incision anterior to the tibiotalar joint.

9. The implant according to claim 1 inserted into a ginglymus joint, the ginglymus joint being a tibiotalar joint, the monolithic implant's first major surface positioned against the tibia, its second major surface positioned against the talus, and the protrusion proximate the implant's anterior side is engaged with a neck of the talus.

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10. The implant according to claim 1, wherein the implant is made of polyurethane having hard and soft segments.

11. The implant according to claim 10, wherein the hard segments are made of oligourethane units formed from diisocyanate and chain extender, and wherein the soft segments are made of polyol units.

12. A monolithic device for implantation into an ankle joint space within the body of a mammal, the device comprising:

a monolithic structure fabricated from a biocompatible, biodurable material that is configured to be inserted into the joint compartment, the monolithic structure including first and second major surfaces, the first major surface curved for positioning against a tibia, such that the tibia can articulate across the first major surface, and the second major surface curved for positioning against a talus, wherein the monolithic device is substantially free of anchoring portions that need to be attached to the bone, cartilage, ligaments or other tissue, wherein the first and second major surfaces curve only in an anterior-posterior direction, and wherein the first major surface is curved differently than the second major surface such that the first major surface is adapted to be congruent with the tibia and the second major surface is adapted to be congruent with the talus, and wherein the monolithic implant is comprised of a polymeric biomaterial that includes both hard and soft segments to provide at least one of desirable wear resistance, congruency, and cushioning properties.

13. The device according to claim 12 wherein stability of the device within the joint space is provided by the congruency of the device to the talus.

14. The device according to claim 12, wherein the monolithic structure is made of polyurethane having hard and soft segments.

15. The device according to claim 14, wherein the hard segments are made of oligourethane units formed from diisocyanate and chain extender, and the soft segments are made of polyol units.

16. A monolithic interpositional tibiotalar implant for use in repairing joints of the ankle, comprising:

a first major surface curved for positioning against a tibia and curved to allow the tibia to articulate across the first major surface; and

a second major surface curved for positioning against a talus, wherein the implant has a protrusion proximate its anterior side configured to engage the neck of a talus to improve fixation to the talus,

wherein the monolithic implant is comprised of a polymeric biomaterial that includes both hard and soft segments to provide at least one of desirable wear resistance, congruency, and cushioning properties, and

wherein the first and second major surfaces curve only in an anterior-posterior direction.

17. The implant according to claim 16, wherein the hard segments are made of oligourethane units formed from diisocyanate and chain extender, and wherein the soft segments are made of polyol units.

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